Simulations of Water Temperature Profiles over the Great Lakes Region at a Fine Horizontal Resolution

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Introduction

The increasing concentrations of greenhouse gases in the atmosphere are expected to cause an unprecedented rise in global temperatures. Changes in climate will have impacts on the lake water temperature and the dynamics and the intensity of stratification, which could disturb the functioning of aquatic ecosystems. The main objective of this study is to assess the impacts of a warmer climate on the Great Lakes basin thermal properties.

To address this problem:

The Hostetler and SimStrat hydrodynamic lake models have been chosen to reproduce water temperature.

The Regional Atmospheric Modeling System (RAMS) simulates a sub-domain of the Earth's climate system and provides heat fluxes to drive the lake models.

To improve the accuracy of the regional model's outputs for climatic change studies, the exchanges at the lake-atmosphere interface are considered by incorporating the lake component at the surface grid.

The Coupled Hydrosphere-Atmosphere Research Model (CHARM) is a version of RAMS in which the Hostetler model has been coupled, and is used in this project. However, since this lake model has shown some limits in simulating deep lakes, work toward the coupling of SimStrat to RAMS needs to done. The first phase of this process consists of testing and comparing lake models when both are driven by observed atmospheric data. Then, in preparation for the full coupling, the outputs provided by RAMS drive the lake model in an uncoupled experiment. This may provide information on the suitability of simulated atmospheric components to reproduce water temperature profiles.

Lake models

The Hostetler and SimStrat lake models are both one-dimensional models.

The Hostetler model:

parameterizes heat diffusion using an eddy-diffusion coefficient. It has been used in numerous applications of coupling with regional climate models.

SimSTrat:

is a *k*-e turbulence lake model that considers the production and dissipation of turbulent kinetic energy (TKE) to evaluate heat distribution through the column. It has never been coupled to a regional climate model (RCM), but has shown excellent skills in simulating water temperature profiles of deep lakes. The recognized advantage of this model is that it includes the effects of internal seiches on the production of *TKE.* Since parameterization of this process is morphometric-dependent, it could not be considered in this study. Sensitivity tests have shown that this limitation did not reduce its accuracy to simulate Great Lakes temperature profiles.

Both models were initially designed to characterize the horizontally averaged lake-water temperature profiles. To increase the spatial resolution of water temperature profiles, they are run in column mode.

Experimental setup

The two lake models are run at each of the lake grid points of a 30 km horizontal resolution stereographic grid encompassing the Great Lakes domain. The models are run in a standalone mode, wherein a common set of atmospheric driving variables are prescribed for a 10-yr period (1992-2001) on an hourly basis.

North American Regional Reanalysis data (NARR) that reproduce atmospheric variables well over the Great Lakes basin (Figure 3) are used as input to the lake models.

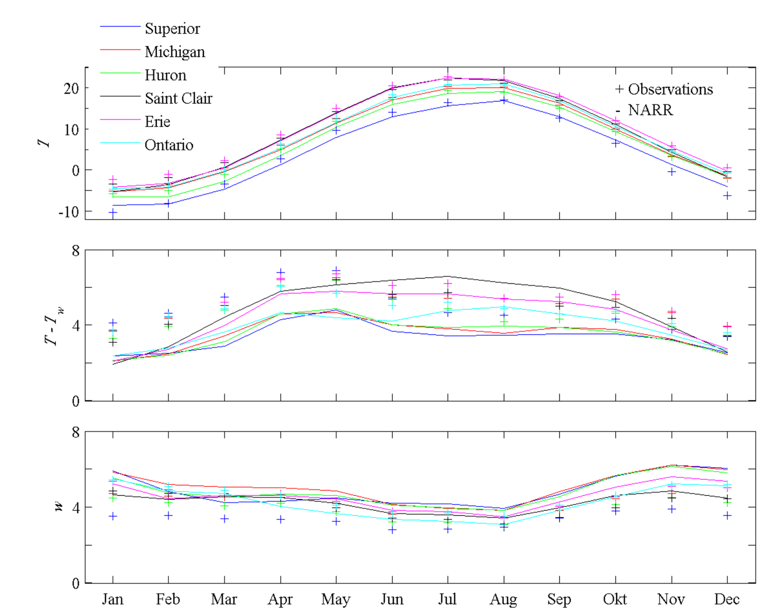

Figure 1. Monthly comparison of lake-average NARR data and surface variables derived from offshore meteorological stations for six lakes in the Great Lakes basin. Except for a small difference in the water vapor amount, variables are in good agreement.

Validation process

Validation and model comparison is made on the basis of vertical water temperature observations from southern Michigan's central basin (Figure 2). Water temperatures are recorded at varying discrete depths (~11). Surface temperatures are provided by National Data Buoy Center buoys during the shipping season. Simulated surface water temperatures of the Great Lake basin are also compared to satellite observations (Figure 3).

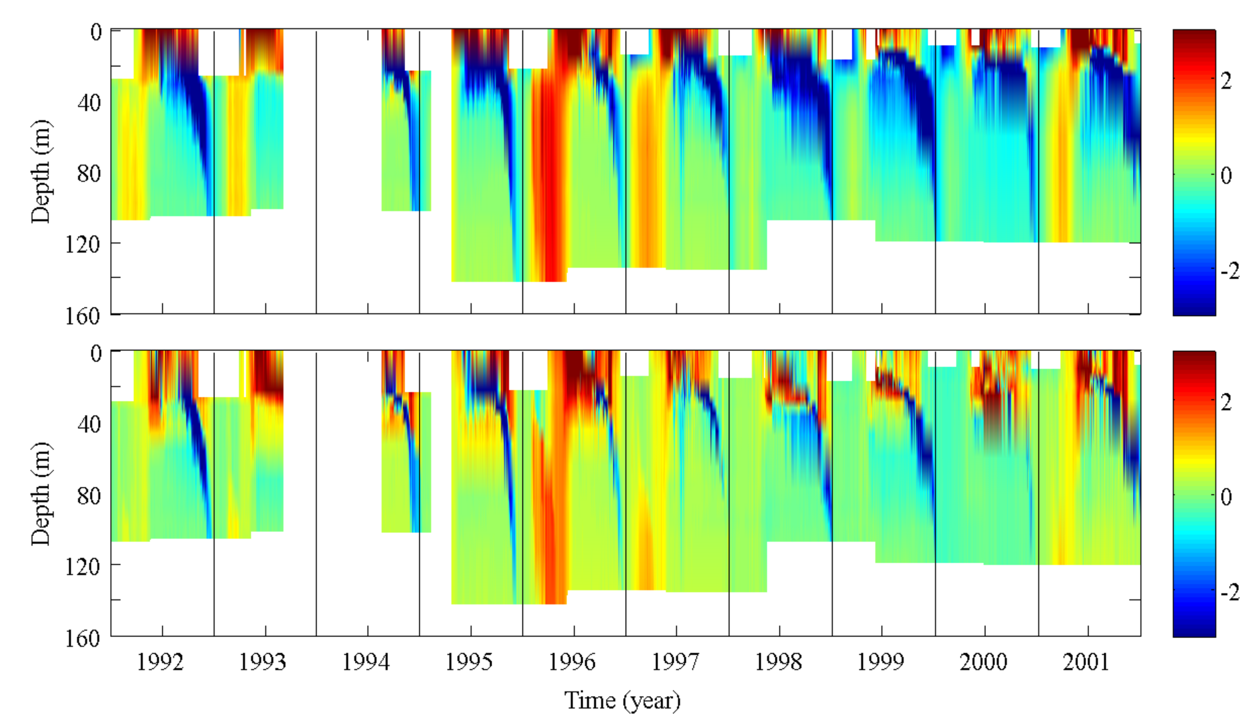

Figure 2. Contour plots of daily temperature difference between simulated and observed water temperature profiles for the (a) Hostetler and (b) SimStrat lake model.

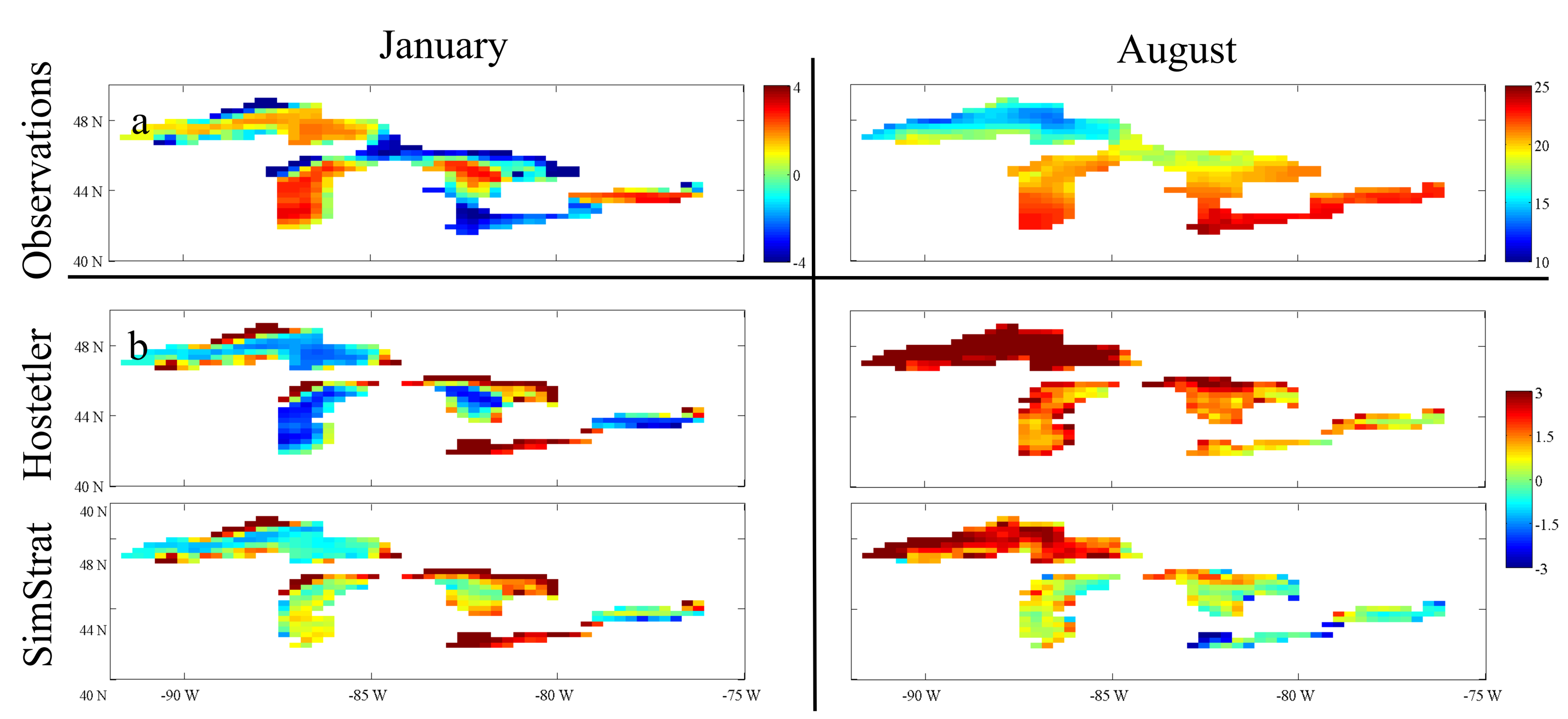

Figure 3. (a) Satellite surface water temperatures over the Great Lake basin, and (b) temperature bias (simulated minus satellite) from runs with both lake models for January and August (average of years 1999-2001) .

Results

Comparison of simulated and observed daily water temperature profiles indicates that both lake models overestimate temperatures from the surface down to the upper metalimnion. This trend is consistent over the whole Great Lakes basin, mainly in summer. This may result from the overestimate of the atmospheric water vapor amounts (insufficient cooling by evaporation) and the earlier ice break up (warming of surface waters too early in spring).

Below 40 m, lake profiles' tendencies are rather different:

- Hostetler model: insignificant interannual temperature variations. The bias thus depends on the initial water temperature profile.
- SimStrat: significantly accounts for seasonal deep hypolimnion temperature variations.

The seasonal evolution of the thermocline is better reproduced by SimStrat.

The surface water temperatures are well simulated by the Hostetler model during the ice-covered periods. The lack of an ice module in SimStrat may be an issue as the lake cannot be isolated from the atmosphere during cold periods.

Coupling of lake and climate models

Lake temperature profiles simulated using NARR or RAMS data as input to the lake models are compared. The main differences are observed in the upper layers (Figure 4) where the bias is mainly due to overestimate of air temperatures in winter in RAMS outputs (~ 5C).

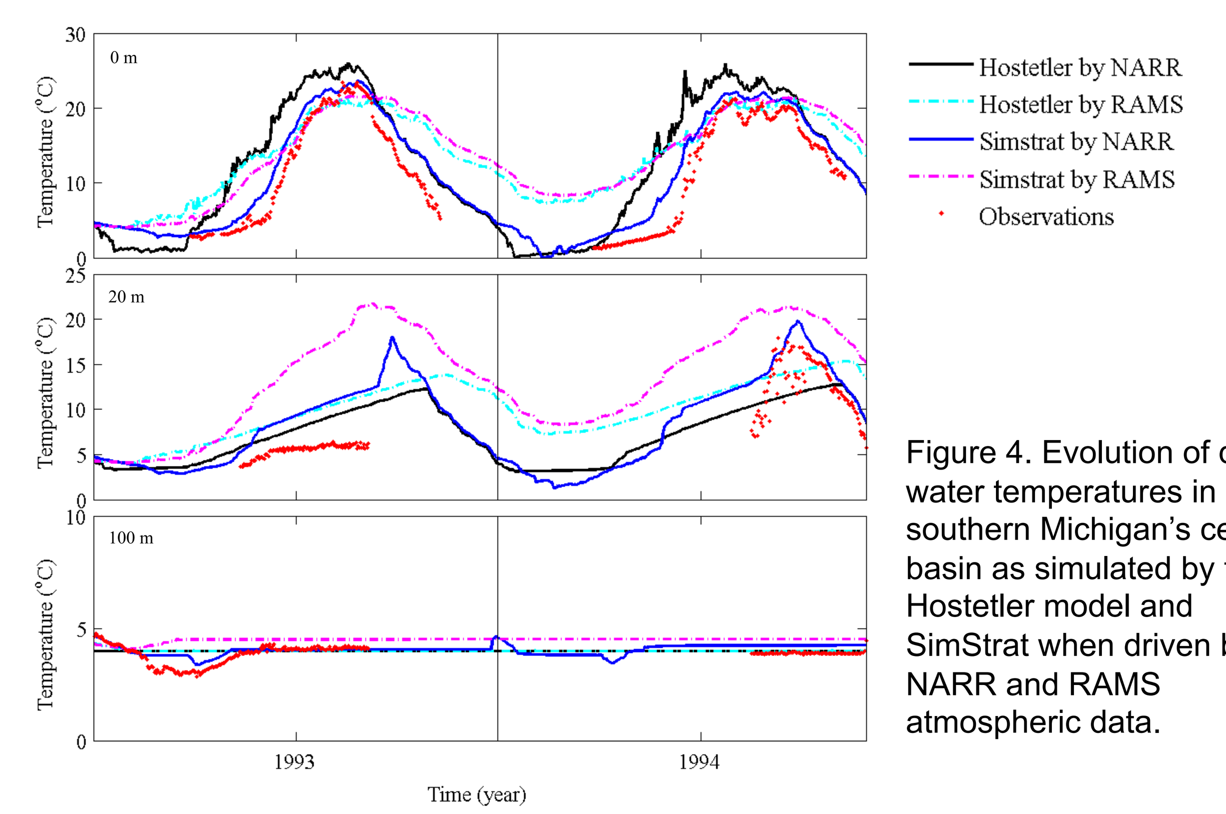

Figure 4. Evolution of daily water temperatures in southern Michigan's central basin as simulated by the Hostetler model and SimStrat when driven by NARR and RAMS atmospheric data.

Future tasks

Work toward the validation of SimStrat for the Great Lakes. This includes:

- implement an ice module.

In addition to the Hostetler model, SimStrat will be coupled to RAMS in an effort to provide accurate water temperature profiles and improve near-surface conditions in long term climate simulations.